Title

Use of injected polymers derived from plastic waste as substitution of fossil carbon and natural gas in electrical arc furnace (EAF)

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Summary

The paper describes development and testing of combined injection of Polymers derived from plastic waste with white slag, oxygen and gas at 160t EAF operated in Ferriere Nord - steel plant of Pittini group in Italy.

Key Words

electric arc furnace, foaming slag, carbon, plastics, burner, injector, oxygen

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Introduction

Use of carbon and natural gas in EAFs is common practice these days. Injected carbon is used mainly for slag foaming and natural gas with oxygen as energy input by burners.

There is a strong effort in the steel sector to replace fossil raw materials with residues from other sectors, in order to reduce the utilization of virgin raw materials and to valorize wastes which are currently landfilled or in general scarcely reused. To fulfil these needs, new burner / injector technology has been developed and tested in EAF as part of Polynspire European research project within Horizon 2020 program. The technology is using precisely controlled injection of polymer particles via burner / injector combined with recycled slag powder injection as well as with oxygen lancing. The expected benefits include environmental improvements due to plastic waste valorisation, reduced fossil materials use as well as potential cost savings and productivity improvements.

Ultimate analysis (dry)	**Plastic residue 3-20 mm**
HHV*(kJ/kg)	
HHV** (MJ/kg)	32.37
Ash (% dry)	9.61
Cl (% dry)	0.38
S (% dry)	0.03
H (% dry)	10
N (% dry)	1.1
C (% dry)	64
O (% dry)	14.84
Proximate analysis (dry)	
Volatile matter (%)	88.89
Ash(%)	9.61
Fixed carbon (%)	1.5

Figure 1 - Plastic residues (polymers) chemical composition

Injected material characterization

Polymers derived from plastic waste have been analysed in terms of its chemical and physical properties. The chemical analysis of the material under concern is shown on Figure 1. The carbon content in the plastic residue is 64% but only the 1.5% is fixed, the remain part is bonded with other elements (oxygen, hydrogen etc.).The major part of the plastic is constituted by volatile matter (88.89%), the fixed carbon content, calculated as difference is just 1.5%. Thermodynamic analysis has been

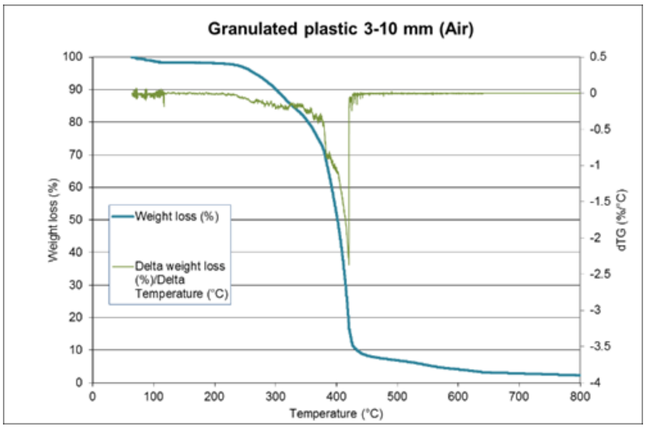

Figure 2 - Weight loss (TG) and its variation (dTG) v.s. temperature

performed to understand material behavior with increased temperature in air as well in nitrogen. Particles behavior was the same in air as in nitrogen.

On the basis of the Figure 2 the following considerations can be done:

1) The behavior of the plastic residue (polymers) sample is the same both in air and in nitrogen it confirms that the plastic residues combustion occurs thought the following subsequent steps:
   a. Mass transfer of volatile matter from particle to surrounding environment.
   b. homogeneous combustion of material volatile.
2) The plastic residue devolatilizes in two phases between 250 and 450°C. In the first phase the 25% of the light organic matters volatilize in the range of 250-350°C; in the second phase the 75% of the heavy organic matters volatilize in the range of 350-450°C.
3) The dTG shows that there are different types of picks in this range, that can be referred to different types of plastics and/or organic molecules devolatilization.

The maximum kinetic devolatilization occurs between 420-440°C.

Bulk density of polymers is 0.3t /m3, which is less then 50% of anthracite coal powder.

From the above, it is obvious that the material has very different chemical and physical characteristic than anthracite coal typically used as foaming slag agent in EAFs, hence different approach needs to be considered to use polymers in EAF.

Injection Equipment

The polymers selected for industrial “hot” testing in EAF have been firstly tested in HTT “cold” testing facility to verify behavior during storage, filling from silo to pressure vessel and finally pneumatic injection through pipeline and hoses system to the injection lance. The testing facility is shown on Figure 3

Figure 3 - Testing facility for pneumatic injection

As mentioned, the bulk density of these plastics materials is only around 0.3 t/m3. Low density and shape of particles required use of dynamic pressure control in the vessel combined with rotary valve with precisely controlled revolutions. Due to variation of back pressure also flow of transport air has to be measured and controlled to ensure smooth and well regulated material flow. After testing and material verification, the final equipment design for industrial installation at Ferriere Nord. The full system parameters are listed below

- Storage silo with 100m3 capacity with integrated material extractor
- Injection dispenser – 3m3 volume – single outlet with proportional pressure control combined with volumetric dosing by rotary valve
- Material flow rate controlled from 5 to 25 kg/min with +- 2 kg/min accuracy.

System installation is shown on Figure 4

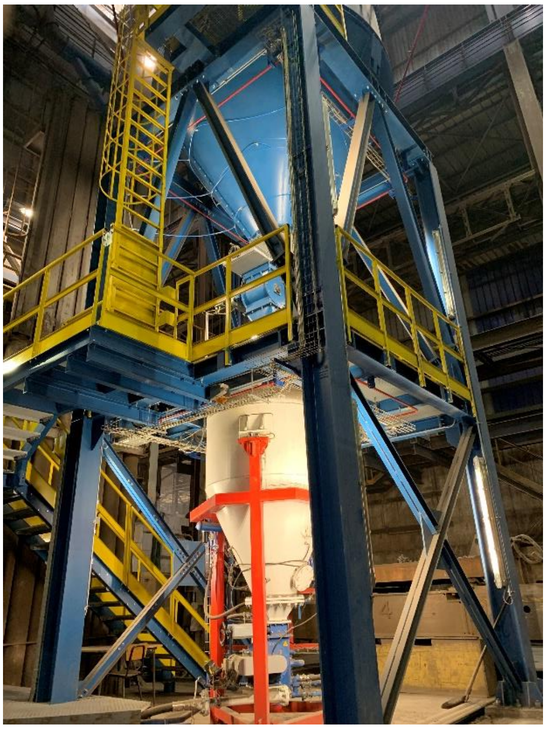

Figure 4 - Injection system installation

Injection to EAF

Combination of low density and low temperature of gasification require to:

- Maximize energy of injected particles
- Control temperature in injection zone to avoid too fast reaction before particles properly mix with slag and steel
- Ensure fast mixing of steel and slag with injected material to promote efficient reactions when particles are injected as carbon substitution
- Ensure that particles are injected with efficient angle and distance to liquid steel and that the injector is able to survive in this harsh furnace environment

To achieve these features, it was decided to design combined unit with supersonic oxygen / gas burner with integrated lances for plastic (polymer) particles and white slag powder, optionally with mixing of white slag and polymers within the lance. To have info on the thermofluid-dynamics related to the system injection lance under typical operating conditions, CFD modelling was carried out within the Ansys-Fluent code frame. Figure 6 shows as example the flow field in the symmetry plane, with highlight on the injection zone with the main flow core at inlet. The results were encouraging in terms of expected flow pattern so complete installation in EAF was made and an overview is shown in Figure 5.

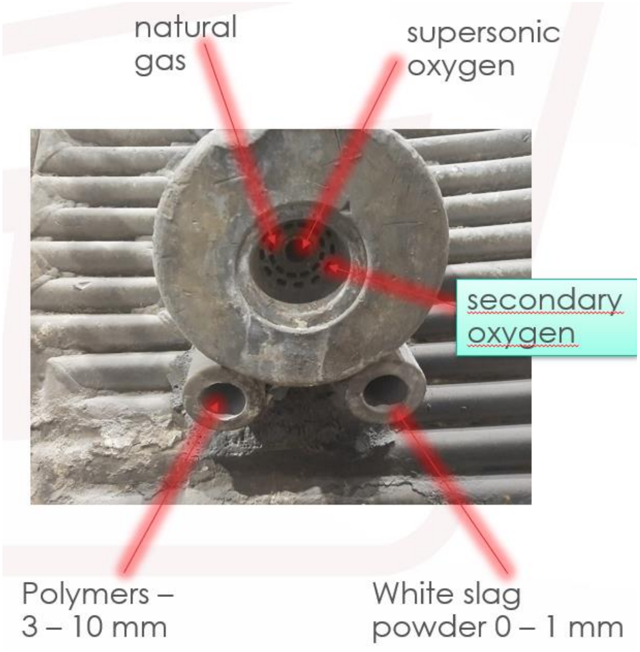

Figure 5 - Installation in EAF panel

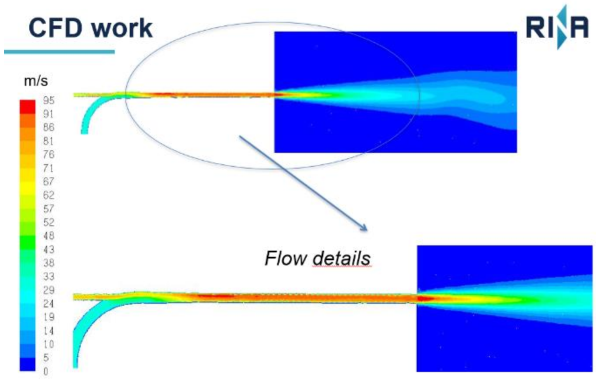

Figure 6 - Injection lance flow pattern : CFD modelling result

Operational results

Ferriere Nord operates 145t AC EAF with the following characteristics and data

- Dimension: 7100mm dia
- Installed power: 130 MVA+10%
- N.3x3000Nm3/h oxygen lances
- N.7x4Mw burners
- N.3x300Nmc/h bottom oxygen tuyeres
- N.2x300Kg/min lime injectors
- N.2x100Kg/min white slag injectors
- N.3x30Kg/min anthracite injectors
- N.1x30Kg/min polymers injector

Steel grades involved: 20% extra-low carbon, 80% rebar.

Typical and averaged parameters:

- Tap to tap time: 46min
- Average active power: 92 MW
- Total Oxygen consumption: 34 Nmc/t
- Total Natural gas consumption: 5,8 Nmc/t
- Average number of buckets per heat: 2,2
- Total anthracite injected: 1200 Kg/heat

In Figure 7 and Figure 8 the installation location is shown. It has been placed beside the slag door.

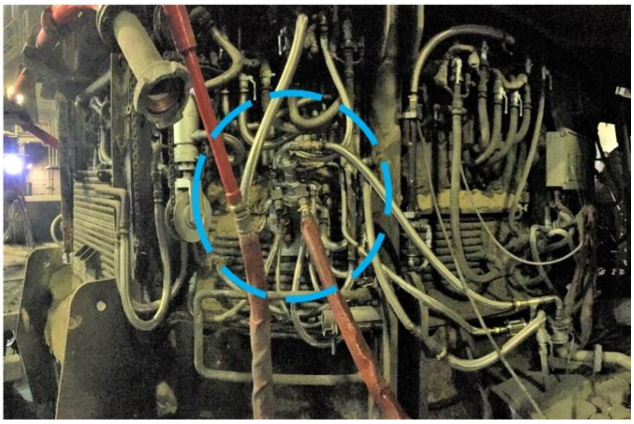

Figure 7 - installation of the injector beside the slag door

Figure 8 - inner view at the EAF of the injector

During standard operation, there are 3 anthracite lances used with a flow of 10 – 25 kg/min.

A large number of trials has been carried out:

- polymers injection in substitution of one of the three anthracite injectors. It consists of approximately 30% reduction of anthracite injected and replacement by an almost equal amount of polymers. Several trials focused on which anthracite injector has to be switched off have been taken into account.

- A first attempt of white slag and polymers mixing has been tried in the same injector. These trials highlighted the complexity of management of two different kind of material with different flowrate.

A measurement campaign at the chimney has been performed both with polymers and without, on the same process configuration. The results highlighted no differences.

In 582 heats the substitution percentage was about 30% (380Kg anthracite replaced by 350Kg polymers). The substitution ratio is more or less 1:1.

In Table 1 some outcomes have been reported. The values are referred to the difference between the heats using polymers and the current ones, without polymers.

Table 1: delta value between the averaged value of each heats characterized by the use of polymer and those without

	DELTA USING POLYMER
Total Harmonic Distortion	+ 1,4%
Sound Pressure Level *(measured nearby EAF)*	- 0,6 %
Average Active Power	- 0,1 %
EAF Specific Electric consumption	- 1,1 %
Metallic yield	- 0,5 %
O2 Consumption	- 1,0 %
CO2/heat emission	- 4,7 %

CONCLUSIONS

Plastic material represents a valid substitute of fossil coal for foaming purposes in EAF process. In order to be used efficiently in the process, the injection process must take into account the different characteristic of the material, as high content of volatile matter and lower density respect anthracite. For this reason, a tailored complete injection system has been designed, installed and tested in the steel factory of Pittini - Ferriere Nord, Italy (FENO).

The FENO EAF melting process is characterized by high variability in scrap composition. Such achieved results could fell into the range of value represented by its standard deviation.

Nevertheless, the results are promising and the substitution of 30% of anthracite with polymer seems possible, so further testing on field will be performed.